Piping integrity Assessment Based on Non – Destructive Examinations During Operation

February, 2014

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1. Introduction

- In recent years, comprehensive programs of structural integrity assessment of pipeline systems were initiated in order to evaluate the remaining duration of their life, to decrease the risk of failure and, respectively, to increase the capacity factor of the plants.
- In these circumstances, the problem of development and implementation of investigation methods which can be applied during operation, possibly with minimal additions when they are absolutely necessary in times of outages, has become of great interest.
- Following these requirements, the company **NUCLEAR NDT Research & Services** has initiated an internal Research – Development–Innovation program for non–destructive examination techniques applicable at high temperature.

1. Introduction(cont.)

- The methodology of investigation during operation of pipelines, consist of the following stages and specific phases:
  - **Phase 1 :** Identification of area/components that potentially are affected by high rates of degradation by **visual examination ,flexibility analyses and corrosion analysis.**
  - **Phase 2 :** Global Monitoring of the pipeline system by **Acoustic Emission**, in two phases: during operation ("AE Condition Monitoring") on the hot (up to temperature of 550°C) and during the hydraulic test (on ambient temperature).

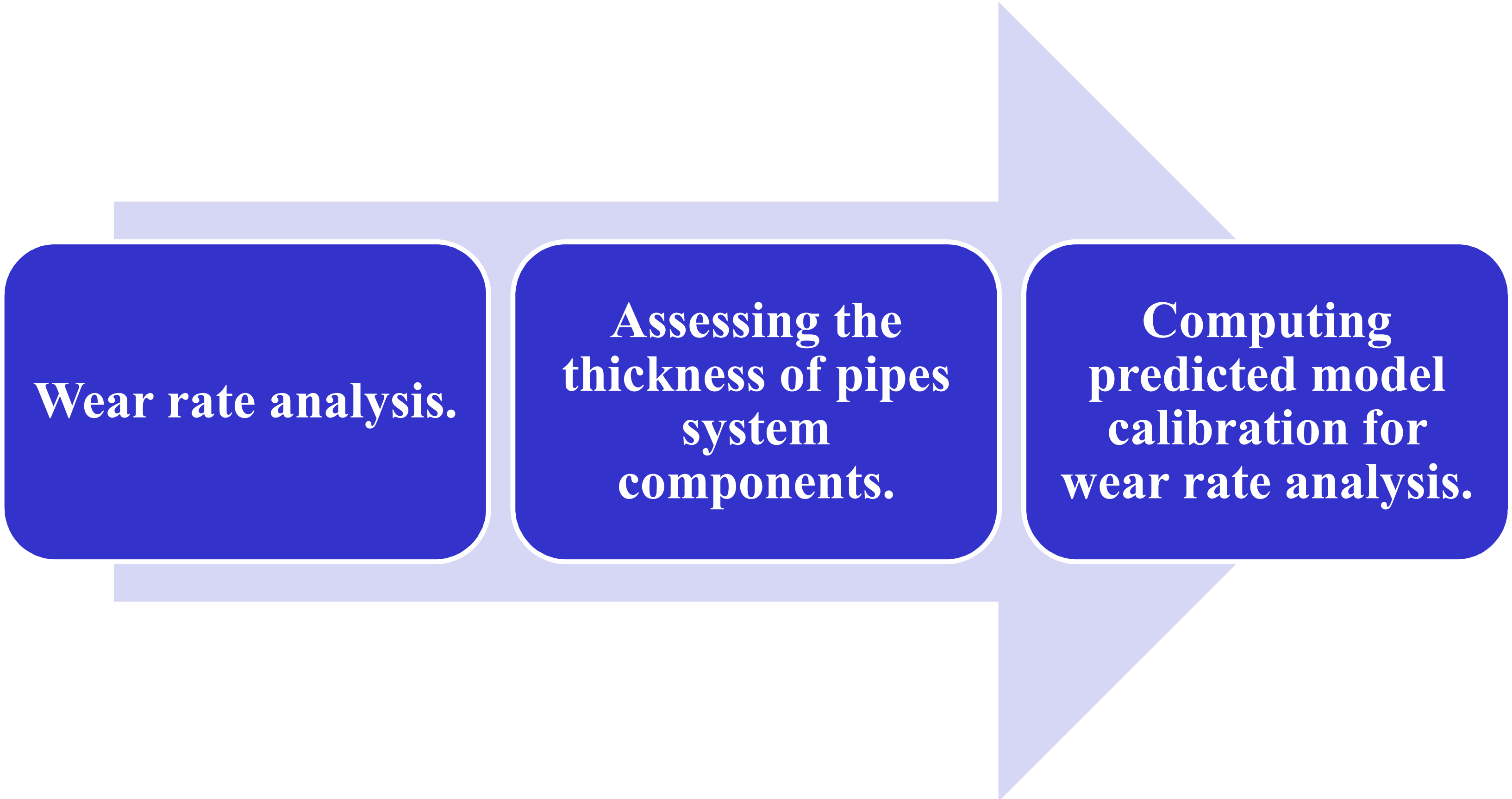
1. Introduction(cont.)

- **Phase 3 :** Examination of area /components potentially affected by high rates of degradation. On this areas, nondestructive examination are performed during operation, by specific techniques, as such: **liquid penetrant examination** (up to 200°C); **magnetic particle examination** (up to 427°C); **ultrasonic thickness determination** (up to 540°C), **ultrasonic examination** of welds and base material(up to 300°C), **radiographic examination** of welds (up to 500°C).

1. Introduction(cont.)

- Final validation of the methodology developed by **NUCLEAR NDT Research & Services** for assessing the structural integrity and remaining life duration of pressure equipment based on methods and techniques of nondestructive examination during operation, was performed on oil refinery plants by investigations on a large number of significant technological piping systems, steam pipes and pressure vessels (more than 200 pipes and 25 pressure vessels).

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.



Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

Compare thickness measured according to design of piping components under internal pressure and NNDT PL-11-2 (Nuclear NDT procedure - minimum thickness required for bearing pipes components on supports).

Evaluate remaining service life considering long term corrosion rate (LT) and the greatest pipe system corrosion rate.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

Remaining life calculations (API 570):

$$Remaining\ life = \frac{t_{actual} - t_{required}}{corrosion\ rate}$$

t_{actual} = actual thickness measured at the time of the inspection for a given location.

$t_{required}$ = required thickness at the same location.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

LT (long term) corrosion rate determination (API 570):

$$Corrosion\ rate(LT) = \frac{t_{initial} - t_{actual}}{time\ between\ tinitial\ and\ tactual}$$

t_{actual} = actual thickness measured at the time of inspection.

$t_{initial}$ = thickness at the same location as actual measured at initial installation.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

ST (short term) corrosion rate determination (API 570):

$$Corrosion\ rate(ST) = \frac{t_{previous} - t_{actual}}{time\ between\ tprevious\ and\ tactual}$$

t_{actual} = actual thickness measured at the time of inspection.

$t_{previous}$ = thickness at the same location measured at previous inspection.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

Corrosion rates shall be calculated on either a short-term or a long-term basis.

If calculations indicate that an inaccurate rate of corrosion has been assumed, the rate to be used for the next period shall be adjusted to agree with the actual rate found.

MAWP (maximum allowable working pressure) determination:

The MAWP for the continued use of piping systems shall be established using the applicable code.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

Required Thickness Determination:

The required thickness of a pipe shall be the greater of the pressure design thickness or the structural minimum thickness.

Assessment of Inspection Findings:

Pressure containing components found to have degradation that could affect their load carrying capability shall be evaluated for continued service.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

Fitness-For-Service techniques, such as those documented in API 579-1/ASME FFS-1, Second Edition, may be used for evaluation.

The Fitness-For-Service techniques used shall be applicable to the specific degradation observed.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

For each measured component a Line Correction Factor is computed.

The Line Correction Factor is the median value of the ratios of measured wear for a given component divided by its predicted wear.

One or more physical lines of piping is analyzed together in the Predictive Plant Model.

Predictive plant model methodology uses a relationships to predict the rate of wall thinning due to corrosion or erosion - corrosion and total amount of wall thinning in a specific piping component.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

Predictive plant model calibration is computed in two steps:

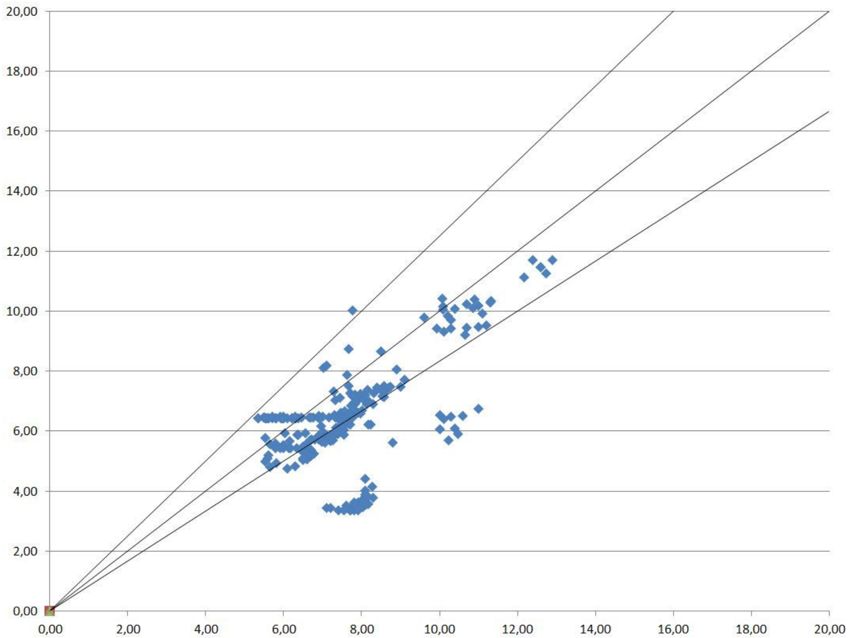
Pass 1 – analysis is based on the Plant Predictive Model, and results of the plant wall thickness measurements are not included.

Pass 2 – analysis is based on results of the plant wall thickness measurements.

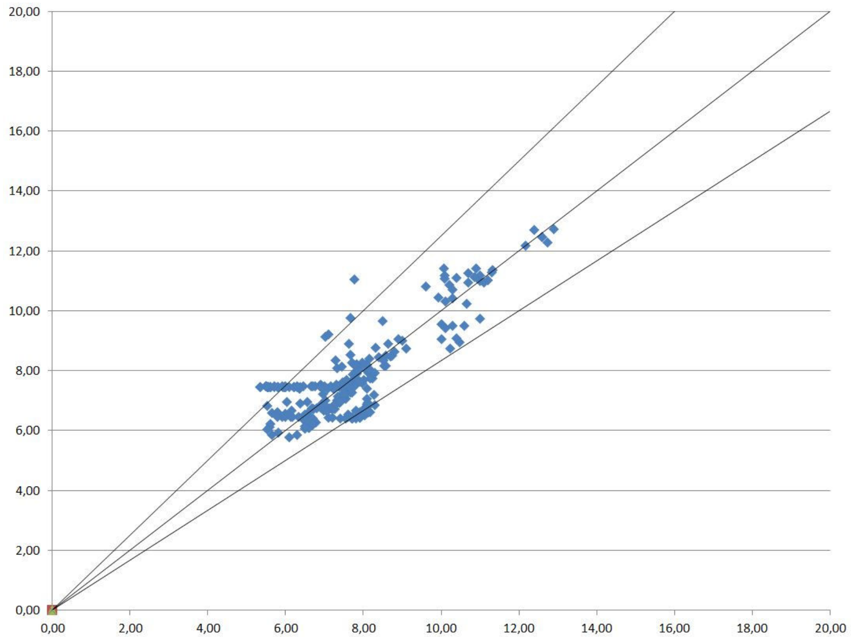
Predictive plant model calibration is used to evaluate the future wall thickness at a specific time.

Wear rate analysis, assessing the thickness of piping system components, predictive plant model calibration.

Pass 1 Analysis



Pass 2 Analysis



Plots of measured / predicted thickness.

Flexibility analysis

- **Purpose** : Identification of areas / components subject to high stress, where we can expect a significant failure probability
- **Reasons :**
  - **Changes** in the piping system since the commissioning :
    - the structure of the materials,
    - diminished wall thickness,
    - changing of supporting system,
    - changing of materials (for instance in emergency reparations).
  - **Fatigue calculations –** the need to estimate the remaining life of the system
  - **Improvements** in calculation methods since the moment of conception of the piping system, thus allowing a more accurate evaluation.
- **Software**
  - **CAESAR II** – state of the art pipe stress analysis which evaluates the structural responses and stresses of piping systems to international codes and standards. CAESAR II is the pipe stress analysis standard against which all others are measured.
  - **COMSOL Multiphysics** – general-purpose software platform, based on advanced numerical methods, for modeling and simulating physics-based problems. It can be used for structural analyses and simulations of fluid flow, heat and mass transfer, hydraulic transients, and acoustics in pipe and channel networks.

Flexibility analysis results

➢ **External loading**

- Forced displacement of supports S10 (elevation 29600) and S12 (elevation 41150), due to the temperature difference between fractionating column 100C1 and pipe PB-100-013 from system 27-1.
- The average temperature of the fractioning column between S10 (185,4°C) and S12 (242,9°C) is 214,15°C. The calculation temperature of the pipe is 140°C, while the measured temperature is around 117°C.
- The results shown below are for T_C = 140°C, i.e. a temperature difference of 74.15°C. In our case, the lower the pipe temperature, the higher the loads to which the pipe is subjected.

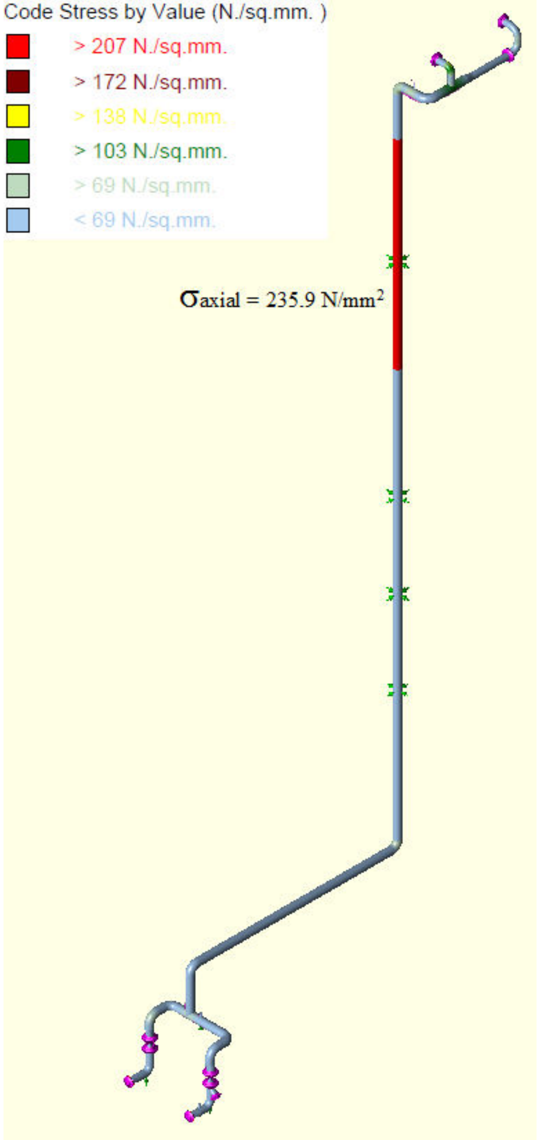


Fig.12: Code stress – operation

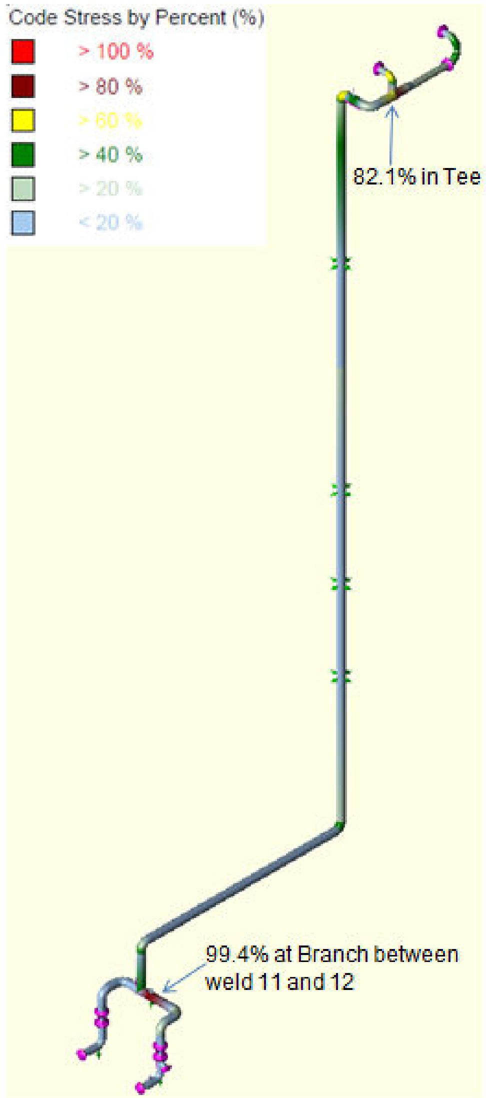


Fig.13: Code stress – weight and pressure

Flexibility analysis results (contd.)

- We performed the flexibility analysis of the system considering the thickness of 3.0 mm on all pipes, excepting the area between support S12 and welding 21 where we considered the thickness of 2.0 mm. The analysis performed with Caesar II shows that axial tension on the portion between the two supports would have a value of 235.9 MPa. In reality this value does not occur as the pipe wall yielded locally around the S12 support.
- The maximum value of the code stress in the pipe, according to the flexibility analysis performed with Caesar II, is reached in the neighborhood of the tee near the SPA support between welding 11 and welding 12.

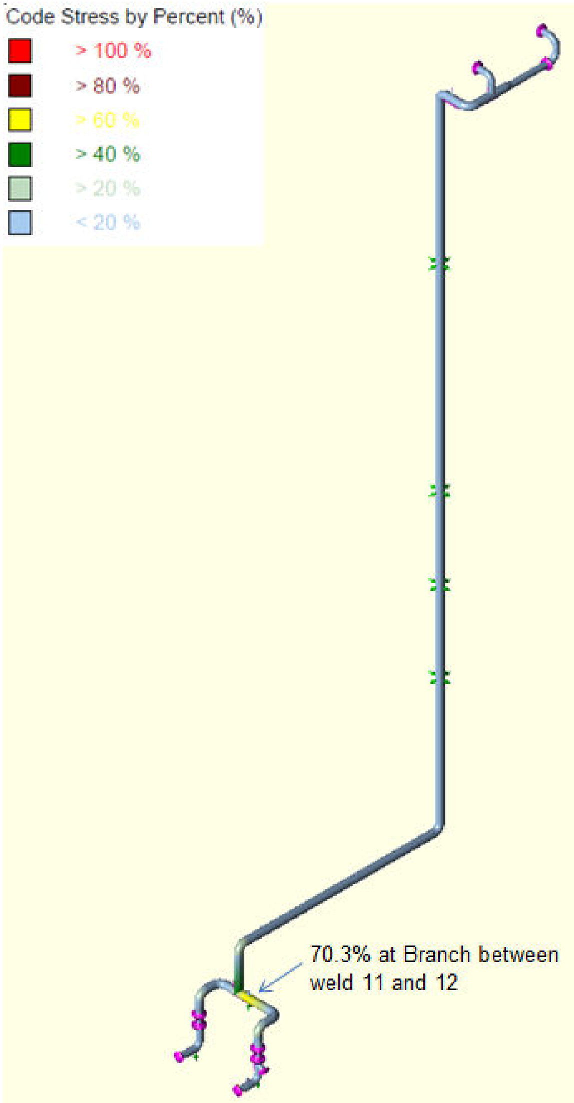


Fig.14: Code stress – thermal expansion

Flexibility analysis results - finite elements local analysis

- The thermal expansion of the fractioning column between the two supports was transmitted to them and the weakest yielded, in this case support S12.
- We conducted a finite element analysis of the pipe imposing a displacement of 12 mm to the support S12 (corresponding to a pipe temperature of 126°C) to illustrate the phenomenon. We considered the pipe thickness of 5 mm, the average measured on the portion between S10 and S12. The design temperature of 140°C should result in a 10 mm displacement, and the measured temperature of 117°C in a 13.1 mm displacement.

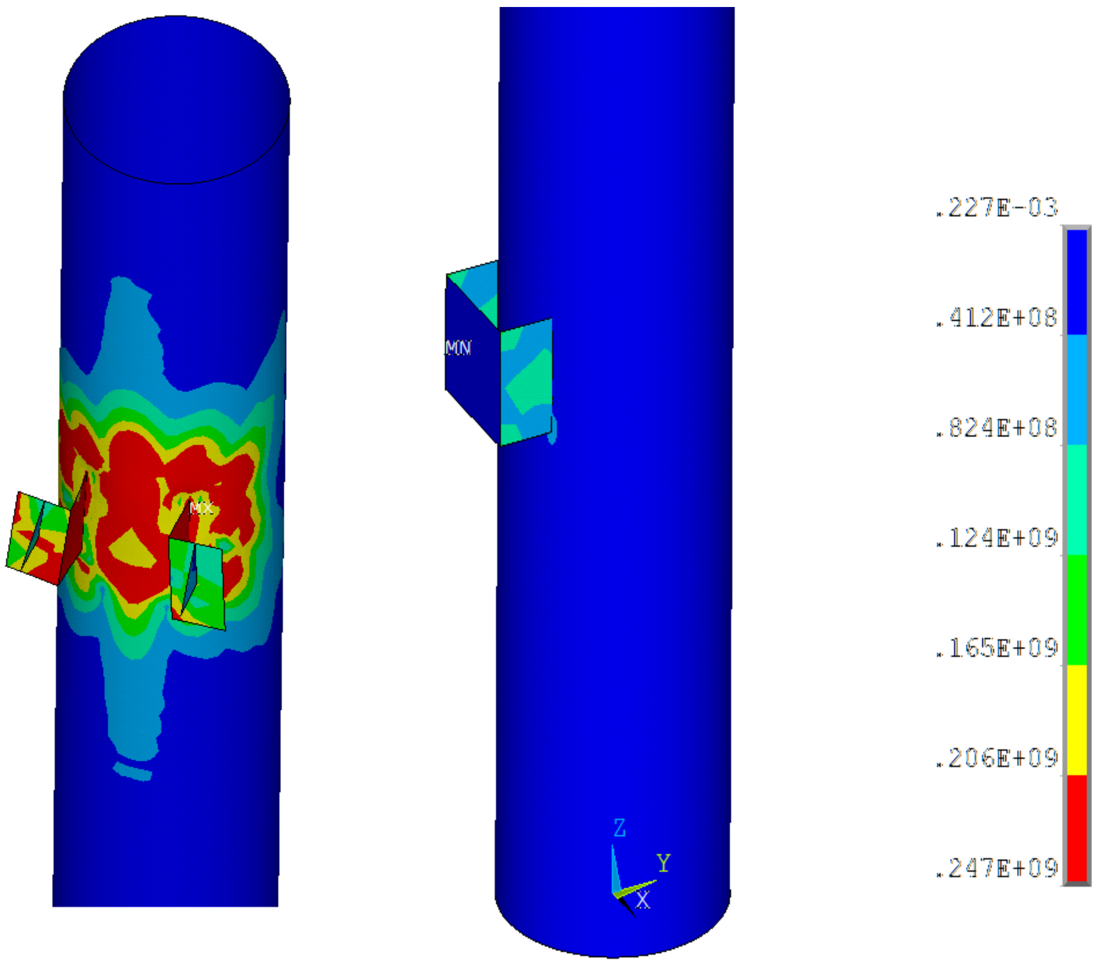


Fig.15: Stress state in the pipe in operation, in the areas around the supports S12 and S10 (the detail shows the area around support S10). Equivalent stress in N/m^2

Flexibility analysis results - finite elements local analysis

- Notice the local deformation of the pipe around support S12, with a depth of about 7.5 - 8 mm towards north, where the guide is missing, and also the large area where efforts are beyond the yield limit. On the ground the measured depth was estimated at 8 - 10 mm.
- As a temporary solution to support the pipeline without stopping the system until the remediation of this situation, we suggest that support S12 should be transformed into a guide and support S10 should be left to carry the weight of the pipe.

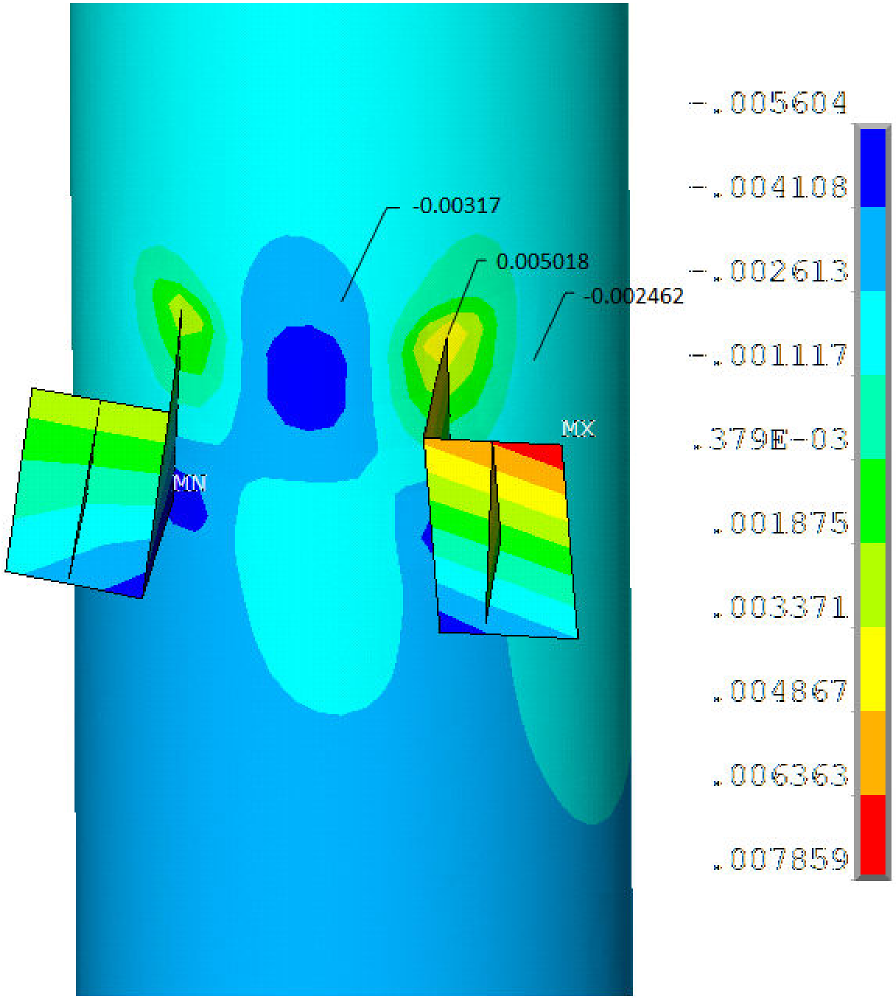


Fig.16: Elastic/plastic deformation around the support S12 (in m).

Flexibility analysis results - finite elements local analysis

- When stopping the circuit, it can be seen that the area where efforts exceed yielding shrinks significantly and a remnant deformation with a depth of about 5.6 mm remains.

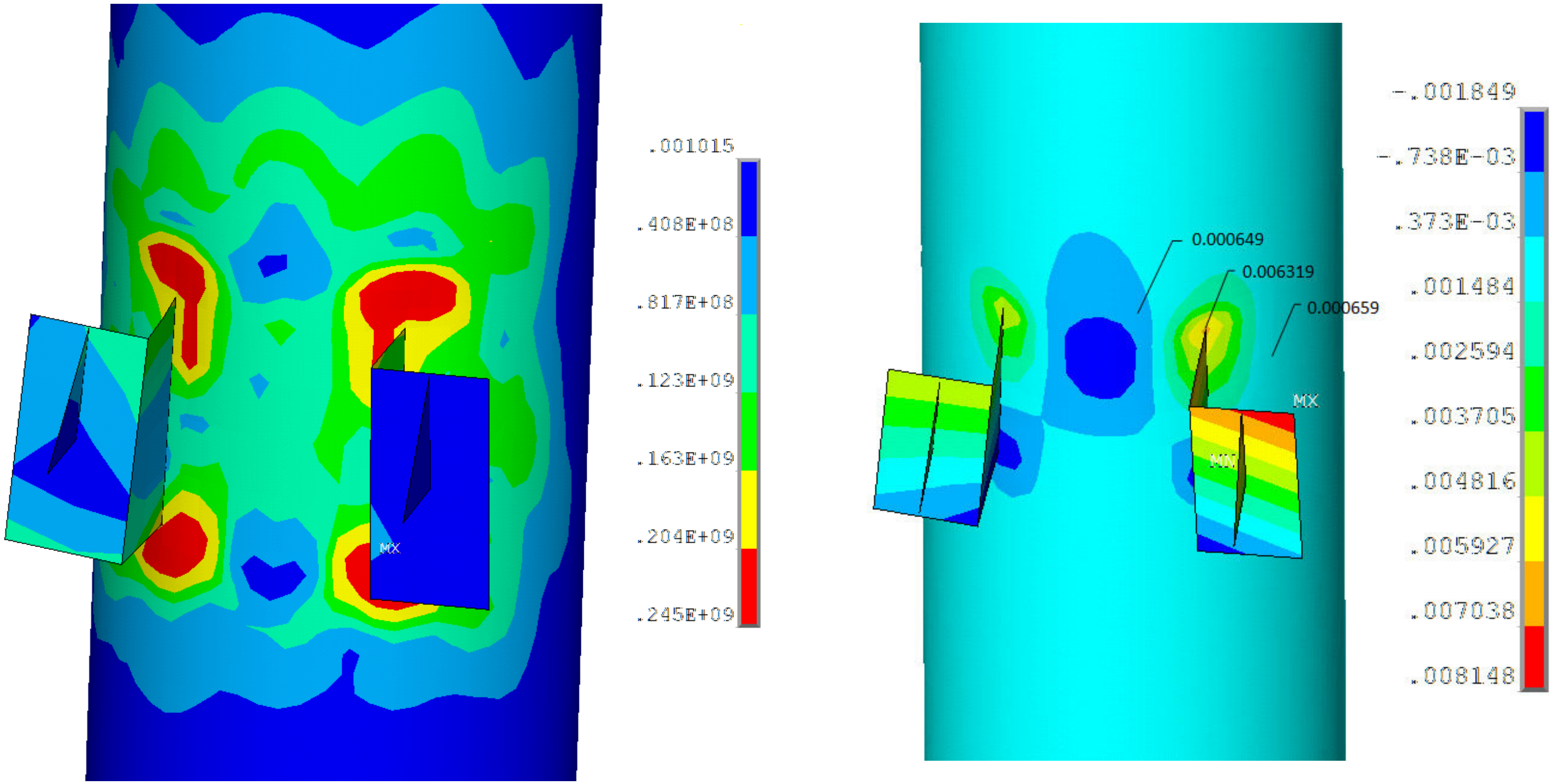


Fig.17: Residual stress (in N/m^2) and local residual deformation in the area around support S12 (in m).

Flexibility analysis : temporary solution

- As a temporary solution to support the pipeline without stopping the system until the remediation of this situation, we suggest that support S12 should be transformed into a guide and support S10 should be left to carry the weight of the pipe.
- The flexibility analysis performed with Caesar II shows that axial stress on the portion between the two supports decreases to the value of 23.6 N/mm^2. The highest value of the code stress is found in the same area, around the tee near the support SPA between welds 11 and 12. The force applied on support S10 is only the weight of the pipeline and has a value of 70.19 kN.

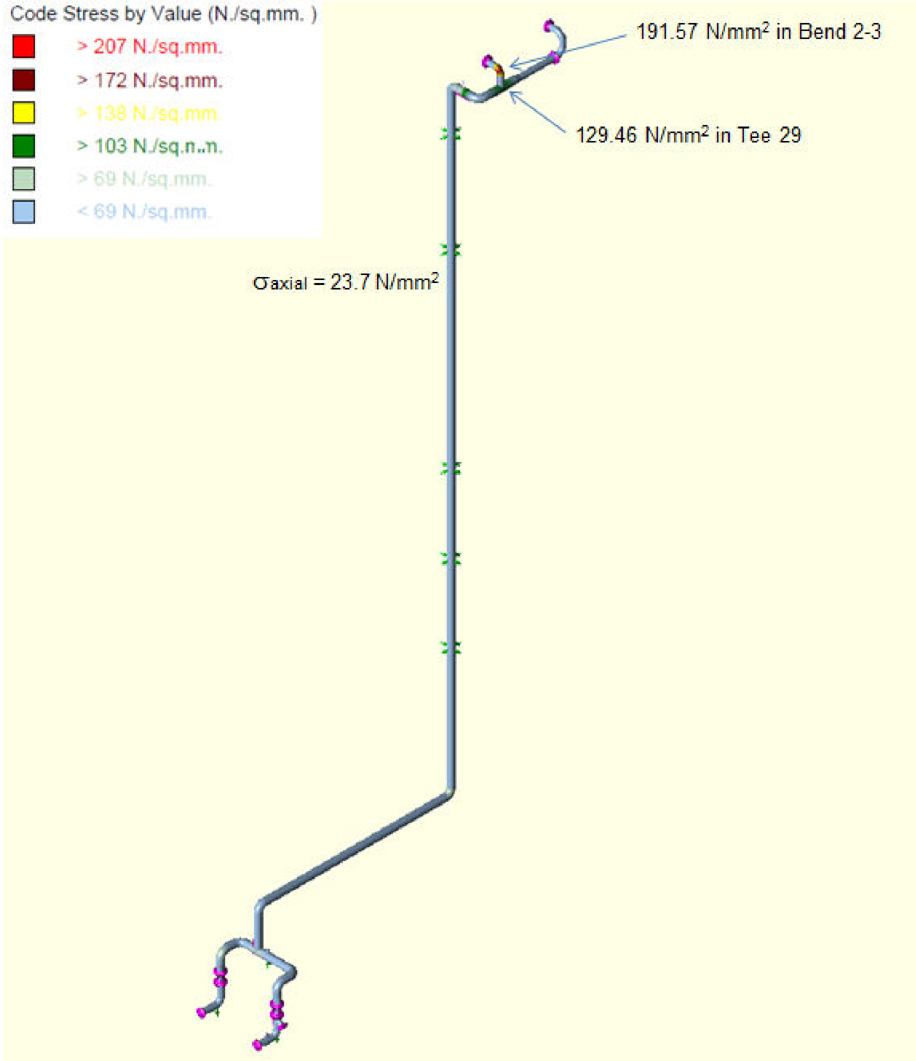


Fig.18: Code stress in operation if the proposed temporary solution is applied

Flexibility analysis :
temporary solution (contd.)

- A finite element analysis of the portion of pipe between supports S10 and S12 was conducted in order to check the stress state around support S10.
- As you can see, the maximum value of stress in the concentration point in the pipe wall is 74.5 N/mm^2, versus an yield stress of 206 N/mm^2 for the weakest steel - A106 gr.A. In the support S10 the maximum stress is 147 N/mm^2 in the concentration, far enough from the yield stress of 206 N/mm^2.

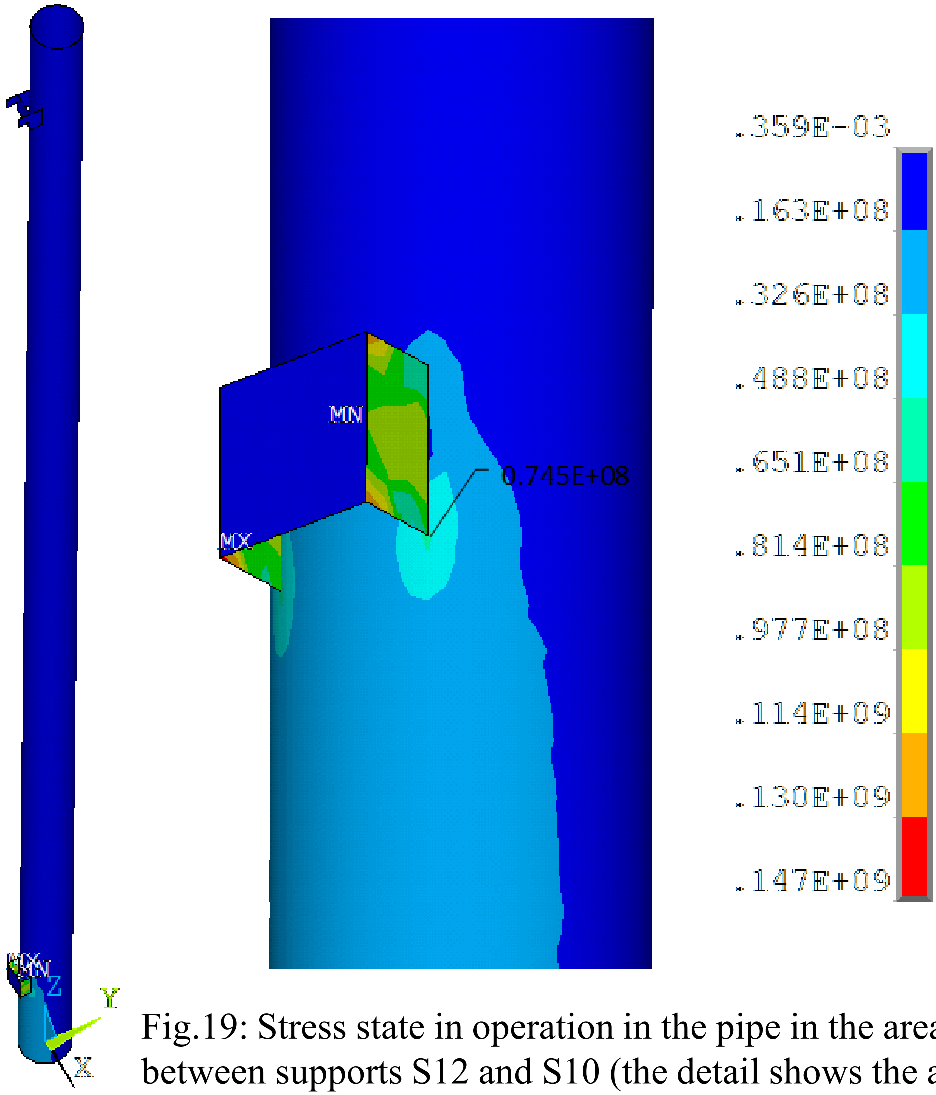


Fig.19: Stress state in operation in the pipe in the area between supports S12 and S10 (the detail shows the area around support S10). Equivalent stress in N/m^2

Acoustic Emission application

- Global Monitoring of the structural integrity of the pipeline system by **Acoustic Emission** (AE), in two phases: during operation ("AE Condition Monitoring"), on the hot pipes, for enough long periods such that the operating parameters (pressure and / or temperature) suffer significant variations (testing standard of reference: ASTM E 1139); and, respectively, during the hydraulic test – on ambient temperature (testing reference standard: ASTM E 569). For application of **Acoustic Emission** on hot pipes, reliable high signal to noise ratio waveguides were achieved that can be used up to temperatures of 550 °C;

Acoustic Emission equipment

- AMSY 6 with 24 channels – Vallen Germany;
  - ASIP-2 Dual channel processor board;
  - TR-2/512MB Transient recorder module for ASIP-2. 256MB per channel.
- AE sensors, 10÷1000 kHz, resonance at 75, 150 or 375 kHz, integrated preamplifier (34 or 40 dB gain);
- Specialized software for AE sources location (linear, planar, spherical, tank bottom, solid and cuboid location);
- Specialized software for recognition and classification pattern;

Acoustic Emission during operation (case study)

Acoustic emission examination of steam pipe with ND 150 mm.

- Duration of examination: 14 hours;
- Temperature recorded during the test: 195÷200 ^{0}C;
- Pressure recorded during the test: 13.2÷14.8 bar;
- Sensors used: VS 150 RIC – 4 pcs. and VS 75 SIC – 4 pcs.;
- Spectrum range: VS 150 RIC - 95÷300 kHz, VS 75 SIC - 50÷300 kHz;
- Coupling conditions: waveguide coupling;
- Total length of examined pipe: 25 m;

Acoustic Emission during operation (case study)

- Examination results:
  - 5 active sources and 1 inactive source

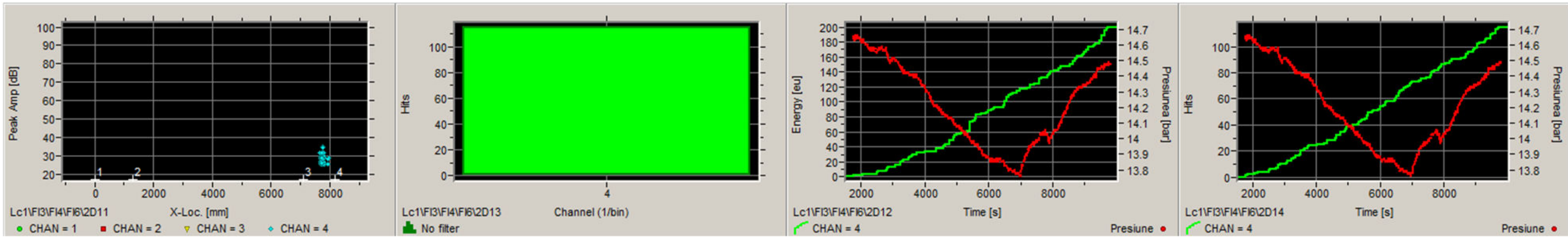


Fig.1 Active source

- NDT follow-up:
  - All active sources were examined with VT, MT, PT and RT;
  - Inactive source was VT examined;
- Two of active sources representing buttwelds of T-pieces were rejected on NDT follow-up. One of them was an outside crack revealed by MT and PT and other was an inside defect revealed by RT.

Acoustic Emission during pressure test (case study)

Acoustic emission examination of diesel fuel pipe with ND 350 mm.

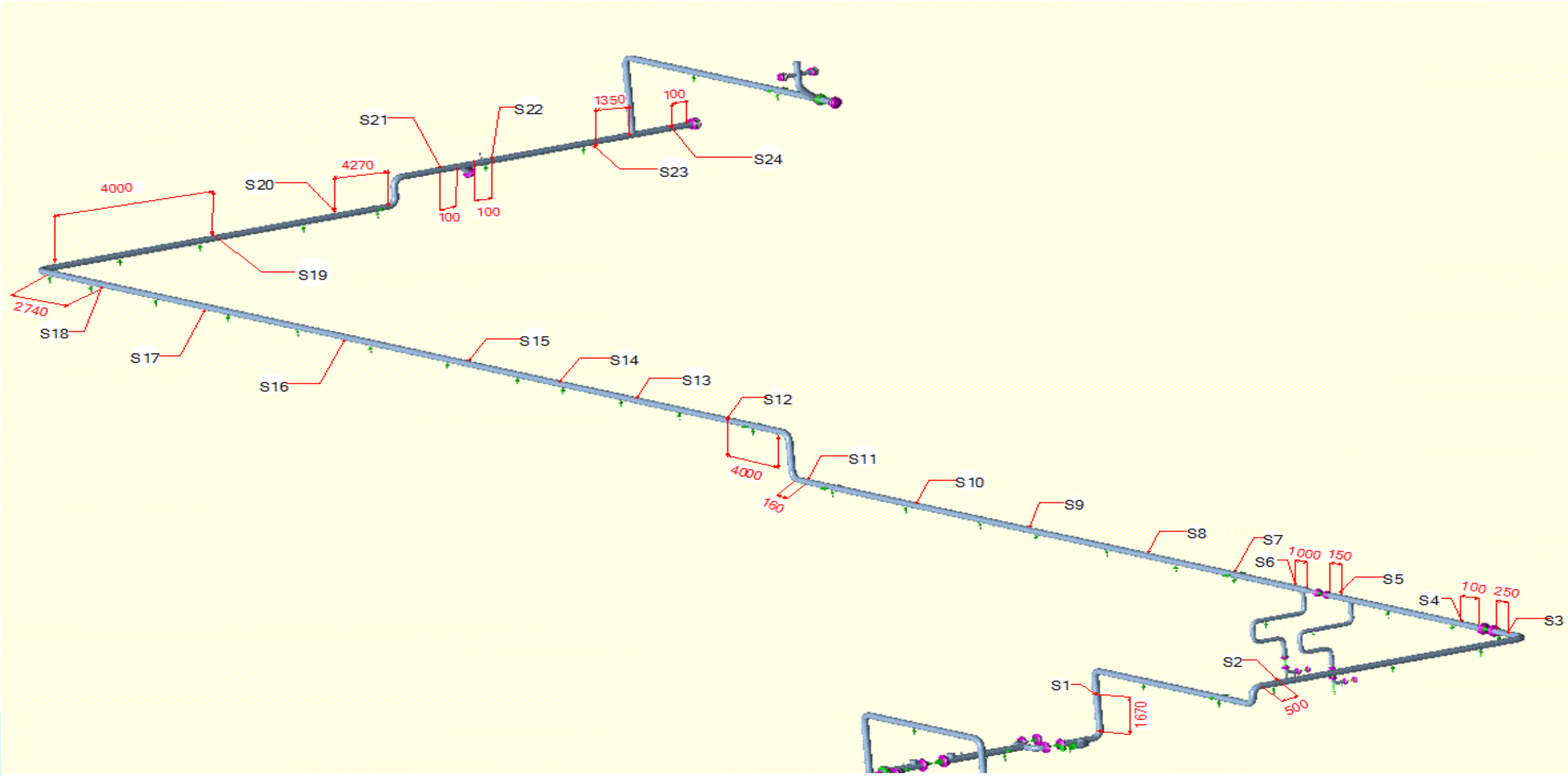


Fig. 2 – Sensors position

Acoustic Emission during pressure test (case study)

- Duration of examination: 2 hours;
- Temperature recorded during the test: 8÷10 ^{0}C;
- Pressure recorded during the test: rise and fall of 0÷10 bar;
- Sensors used: VS 150 RIC – 19 pcs. and VS 75 SIC – 5 pcs.;
- Spectrum range: VS 150 RIC - 95÷300 kHz, VS 75 SIC - 50÷300 kHz;
- Coupling conditions: Direct coupling of sensors to surface;
- Total length of examined pipe: 166 m;
- Examination results: No acoustic sources;

Thank you for your attention!